Development of MARS-h for the **HANARO** Safety Analysis

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ABSTRACT

MARS-h was developed in order that it could be applied to the thermal hydraulic safety analysis of HANARO operating at low pressure and low temperature conditions. To assess the prediction capability of MARS-h, validation calculations were performed against available experimental data of HANARO and other research reactor. The results of validation calculation showed that the developed MARS-h can appropriately be used for analyzing the thermal hydraulic transient of HANARO.

1. Introduction

The MARS (Multi-dimensional Analysis of Reactor Safety) code[1], which is being developed and verified by KAERI, is a realistic system transient analysis code that can be used for the simulation of a wide variety of PWR system transients. This code is a unified version of 1-D reactor system analysis code, RELAP5/MOD3 and 3-D reactor vessel analysis code, COBRA-TF coupled with 3-D reactor kinetics code, MASTER and containment code, CONTEMPT4.

On the other hand, for the safety analysis of HANARO (Highly Advanced Neutron Application Reactor)[2] operating under low pressure and low temperature conditions, a reliable analysis code was necessary. Thus, the MARS code was modified into MARS-h to properly simulate the unique HANARO characteristics such as the finned fuel and the plate type heat exchanger. Major modifications were made on the package of heat transfer correlations since it significantly affects the calculation results. The heat transfer correlations were developed and selected carefully based on the experimental data for HANARO fuel. Heat exchanger model was also developed to reproduce manufacture pressure drop data by manipulating flow area, length and loss coefficient with fixed volume. The heat transfer correlation for a heat exchanger provided by manufacture was implemented in the code.

The objective of this work is to develop MARS-h for the HANARO safety analysis and to perform validation calculations with HANARO and research reactor (RR) test data.

To assess the prediction capability of MARS-h, simulations for single pin heat transfer experiments and plate type heat exchanger performance test were made and compared with experimental results and manufacturer's data. The natural circulation experiment and the selected IAEA benchmark tests for a research reactor were also simulated to evaluate the performance of the code. The system behaviors by RELAP5/MOD3 and MARS-h were compared through the simulations on HANARO transients. The assessment results showed reasonable agreements with test data.

2. Modifications of MARS

MARS code was modified to MARS-h for the HANARO application. Major modifications were made to the heat transfer correlations since they significantly affect the calculation results. The built-in heat transfer correlations were replaced with those developed and selected carefully based on the experimental data and the operating conditions for the HANARO fuel. The modified heat transfer correlations[3] are a single and two phase heat transfer, the onset of nucleate boiling (ONB), the subcooled nucleate boiling heat transfer and critical heat flux (CHF) correlations. A separate heat exchanger model was also developed to reproduce the data of the heat transfer and the pressure drop provided by the manufacturer since both the heat transfer and the pressure drop characteristics for the plate type heat exchanger installed in HANARO were quite different from those of the shell and tube type heat exchanger usually used in PWR.

3. Validation Calculations

Some calculations were carried out using the modified MARS-h to verify whether the developed and implemented models such as heat transfer correlations and heat exchanger model are working as intended [4]. The results are described below together with the brief test descriptions.

3.1 Single Pin Experiment

1) Test data and model description

The single pin heat transfer test was performed using the electrically heated fuel element simulator (FES) enclosed in a glass tube as shown in Figure 1, which simulated the hydraulic characteristics of the finned fuel element of HANARO fuel[5]. These fins are to enhance the convective heat transfer to coolant and to reinforce the mechanical strength of the fuel element. To confirm whether the modified code works as intended, a total of 32 data including 8 sets of single-phase, ONB, OSV(Onset of Significant Void), and two-phase data, were chosen from the experimental data. The nodalization of the test section for MARS-h simulation is depicted in Figure 1[4].

2) Results

The comparison of the calculated heater surface temperature with the measured is shown in Figure 2. As shown in the figure, the modified MARS-h shows a good agreement with the experimental data for HANARO operating condition.

3.2 Heat Exchanger Model

1) Test data and model description

As the pressure drops and the heat transfer characteristics as well as the channel geometry are quite different from those of the general shell and tube type heat exchanger, a new model was developed to reproduce the manufacturer's data by implementing a new heat transfer correlation and manipulating code input such as flow area, hydraulic diameter and loss coefficient with a fixed real volume. Figure 3 shows the nodalization of the heat exchanger, which uses 12 volumes (volume number was optimized) and the primary and secondary sides coupled to the heat structures located in-between.

2) Results

The predicted heat transfer rate and pressure drop are compared with the manufacturer's data in Figure 4. The calculated results are in good agreement within an average of 2~3% error compared with the test data except in very low flow range. This discrepancy, which occurred in this very low core power range, is judged not to be serious in the simulation of the overall system transient.

3.3 Natural Circulation Test

1) Test data and model description

A natural convection cooling test with a scale-down single heated bundle was performed in a large tank simulating the reactor pool [7] as shown in Figure 5. It was designed to demonstrate the general behavior of the HANARO reactor pool where the decay heat from the core is removed by the pool water re-circulation via flap valves. The bundle used in the test is an 18-element hexagonal array with nominally flat radial and cosine axial heat flux profiles. Coolant temperatures were measured at inlet and outlet of the test section, and then the flow rates were calculated from the relation of temperature and bundle power. The nodalization for MASR-h simulation is also shown in Figure 5 and the atmospheric pressure at the pool surface was used as a boundary condition.

2) Results

The predicted results of the mass flow rate for each power level are presented in Figure 6. The predicted results are similar to the experimental data, even though minor discrepancies of the flow rate are identified. However, these differences, which may be diminished if one use correct input for the frictional pressure loss across fuel bundle, are insignificant and conservatively acceptable in thermal-hydraulic analyses.

3.4 HANARO LOEP Transient

HANARO is an upward flowing light water cooled, heavy water moderated open-tank-in-pool type research reactor with 30 MW_{th}[3]. The nodalization of HANARO for

MARS-h simulation is shown in Figure 7. The reactor core is represented by parallely connected 6 kinds of channels, i.e. a hot channel, an average channel and an unfueled channel for both hexagonal and circular flow channel. The reactor pool surface is connected to a time dependant volume which represents the atmosphere. Other components such as piping and pumps are modeled with proper models of MARS-h[8].

To compare MARS-h with RELAP5/MOD3, simulations for HANARO LOEP transient were calculated by both codes.

1) Event and model description [9]

The occurrence of this event results in the simultaneous loss of primary and secondary cooling pumps, cooling tower fans and a reflector pump for core cooling. And CARs of which the power is class IV dropped immediately since the electro-magnetic switches were de-energized. Then the insertion of SORs followed due to the loss of pump supporting them hydraulically. As the uninterruptible power (class II) is connected to RPS, the reactor can be tripped by reactor protective actions if the reactor meets the condition in which RPS should be actuated. After reactor shutdown, firstly the core cooling should be ensured by coastdown flow due to flywheel and later by the natural circulation.

2) Results

Using MARS-h were calculated the thermal-hydraulic parameters such as flow rates and fuel temperatures. Figure 8 shows the comparison of coastdown flow rates at core inlet and fuel temperature during the LOEP transient by both codes. It can be shown that RELAP5/KMRR gave reasonable predictions of flow rate and temperatures for the long term LOEP transients in HANARO.

3.5 IAEA Benchmark Transients

The 10 MW reactor, SPERT, for the selected benchmark transients[10] is the same reactor model used for the neutronics benchmark computations in IAEA, TECDOC-233. Figure 9 is the nodalization for the following problems. Pool outside was not considered in the model because it was not significant for these problems. The core was modeled with hot and average channel with 21 axial nodes and the specified peaking factors. Core inlet flow rate and outlet pressure were used as boundary conditions.

3.5.1 Reactivity Insertion Transient

1) Event description

At an initial power of 1 watt, 1.5$ of reactivity is inserted into the critical reactor in 0.5 seconds. The trip setpoint of reactor safety system is actuated at 12 MW (120% of nominal power) with a time delay of 25 ms before the control rod insertion is initiated. A linear reactivity insertion of –10$ in 0.5 seconds was assumed at reactor trip.

2) Results

The simulation result for the above event is given in Figure 10. The peak cladding temperature, which may be a most important parameter in this event, is depicted together with the results calculated by other organizations and codes in the figure. MARS-h gives a reasonable result of 166.4 ^{o}C, while others show 149.2 ~ 169.8 ^{o}C. Response of other parameters such as power and coolant temperature was similar with those by others in the reference 10.

3.5.2 Loss of Flow Transient

1) Event description

Fast loss of flow transient is occurred at the 10 MW steady state conditions. Core flow is reduced as $e^{-t/T}$ with T=1 second. Reactor trip is initiated at 85% of nominal flow with a 200 ms delay time before control rods insertion begins. A linear reactivity insertion of –10$ in 0.5 seconds was also assumed at reactor trip.

2) Results

The result of peak cladding temperature is compared with those predicted by other organization in Figure 12. The second peak of the cladding temperature occurred during the flow reversal when the core flow changes from downward to upward direction for natural circulation. The MARS-h gives a reasonably good agreement with other results.

4. Concluding Remarks

MARS was modified into MARS-h for applying to HANARO operating at low pressure and low temperature conditions, and its prediction capability was assessed against the experimental data of HANARO and the IAEA benchmark transients of a research reactor. From the assessment results, it can be said that the MARS-h code could be used for analyzing the thermal hydraulic transient of HANARO. However, further improvement on a void model may be necessary for dealing with the phenomena in high void conditions.

Acknowledgements

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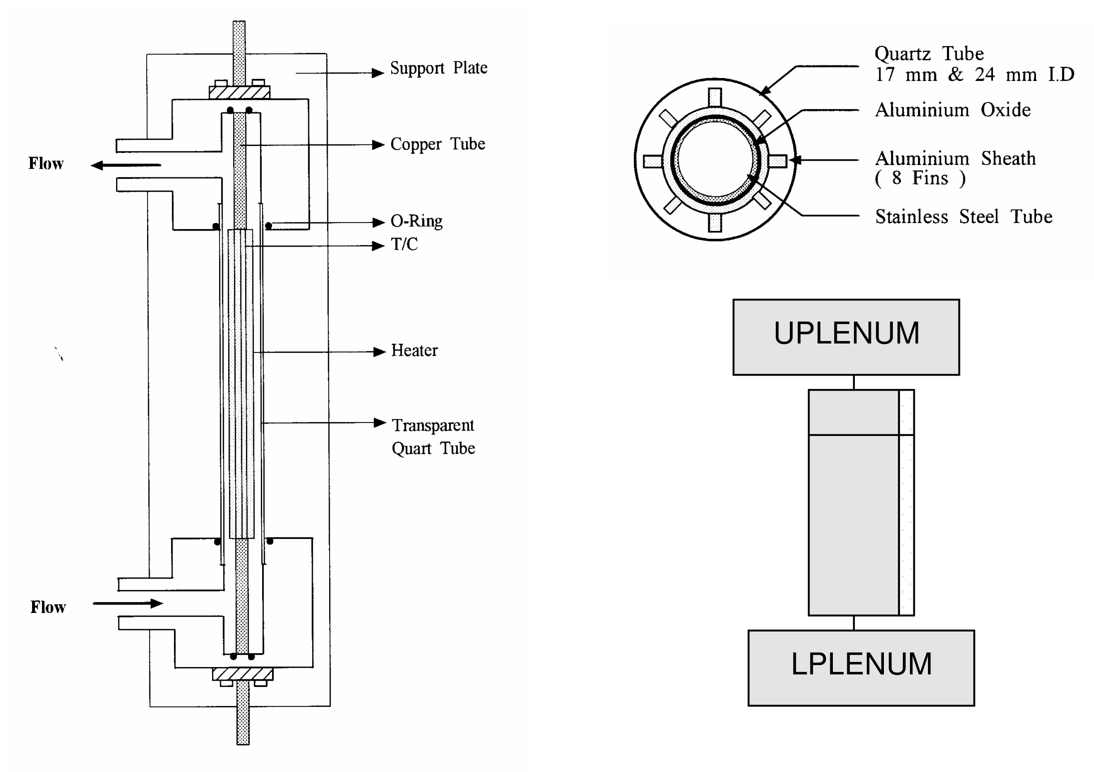

Fig. 1 Test section of single pin heat transfer experiment and nodalization for MARS-h

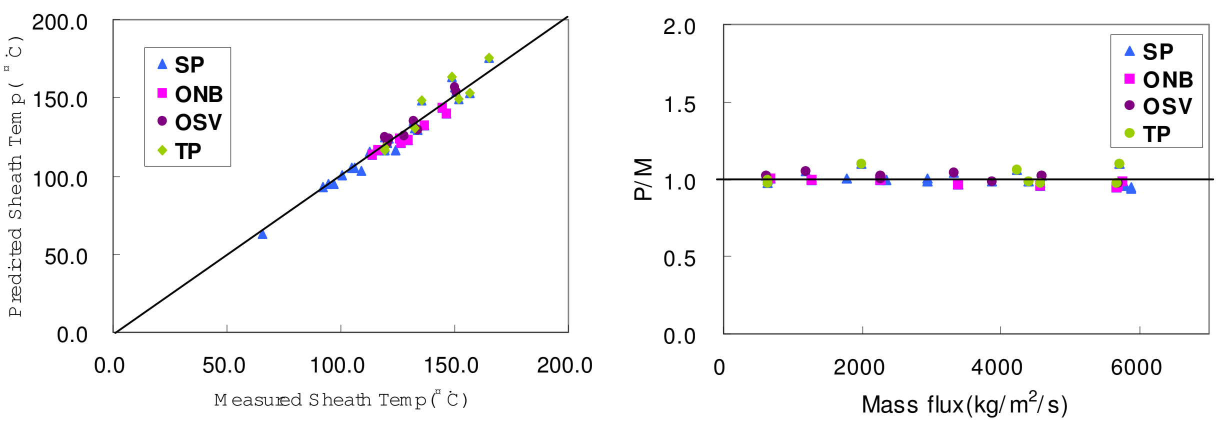

Fig. 2 Comparison of the predicted surface temperature with the measured one

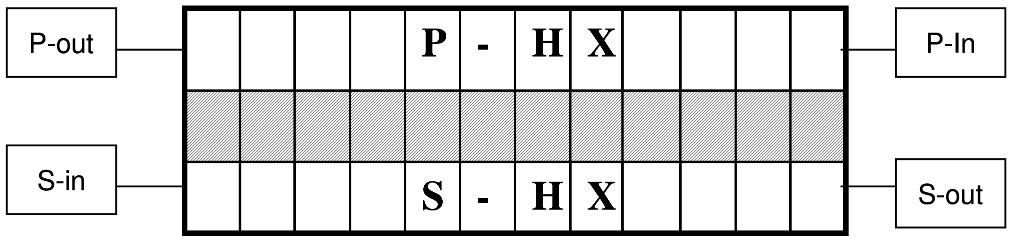

Fig. 3 Nodalization for a plate heat exchanger simulation

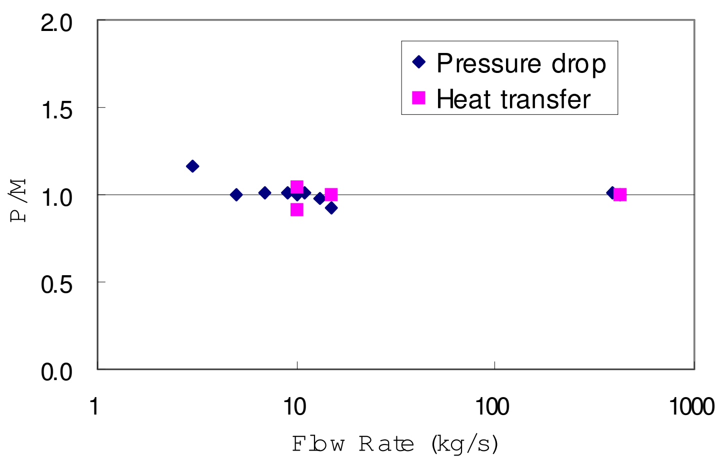

Fig. 4 Comparison of the predicted to the measured values for pressure drop and heat transfer rate

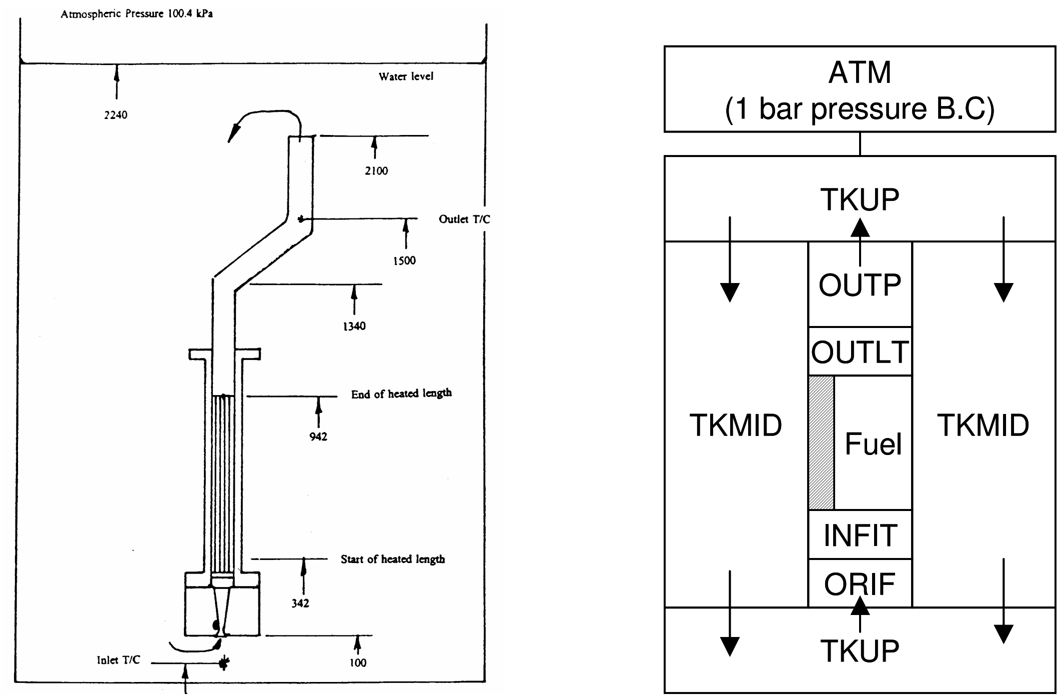

Fig. 5 Schematics of test facility and nodalization for MARS-h simulation

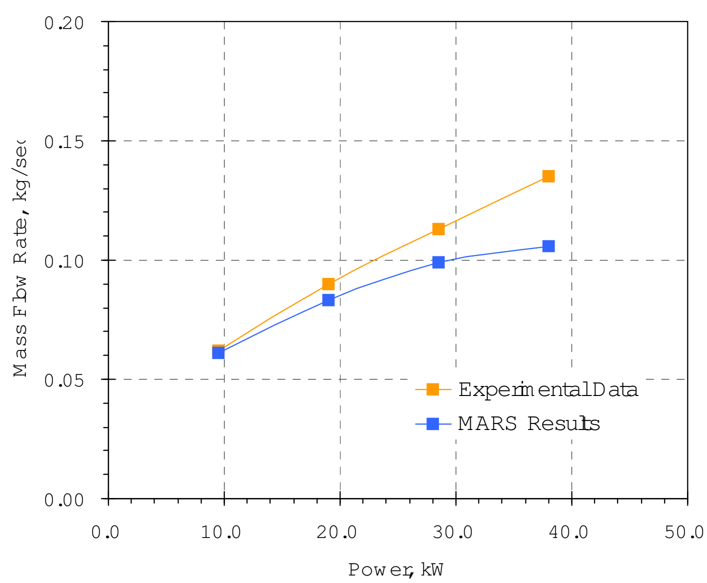

Fig. 6 Comparison of the predicted to the measured flow rate for each power level

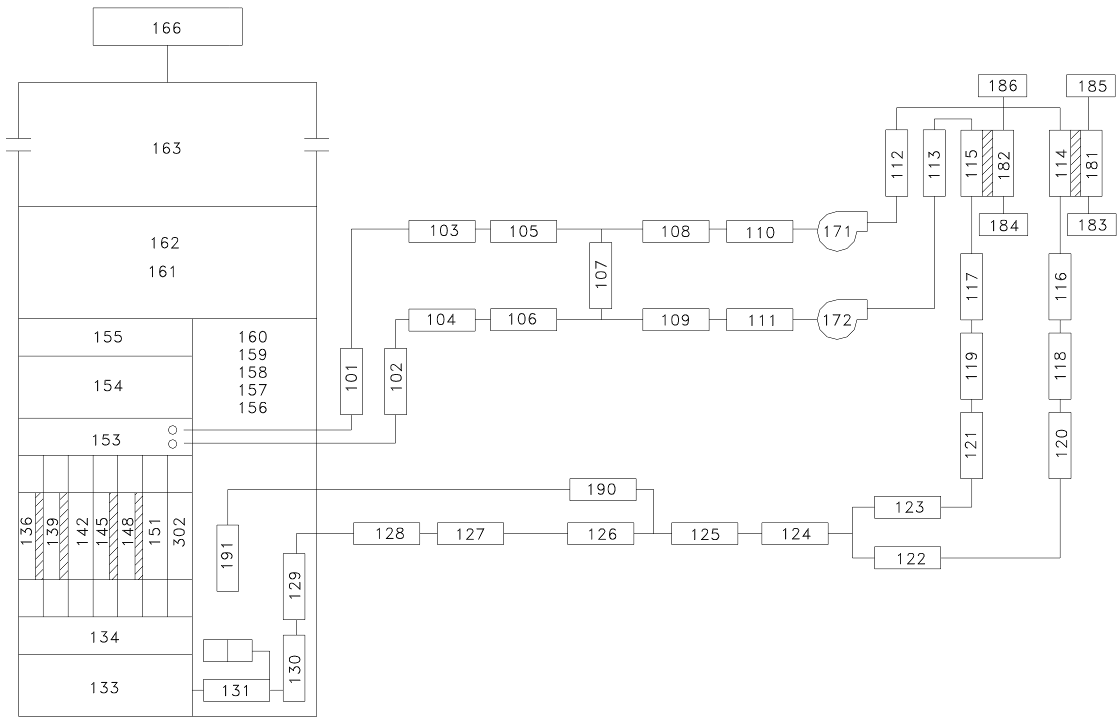

Figure 7. Nodalization of HANARO for MARS-h

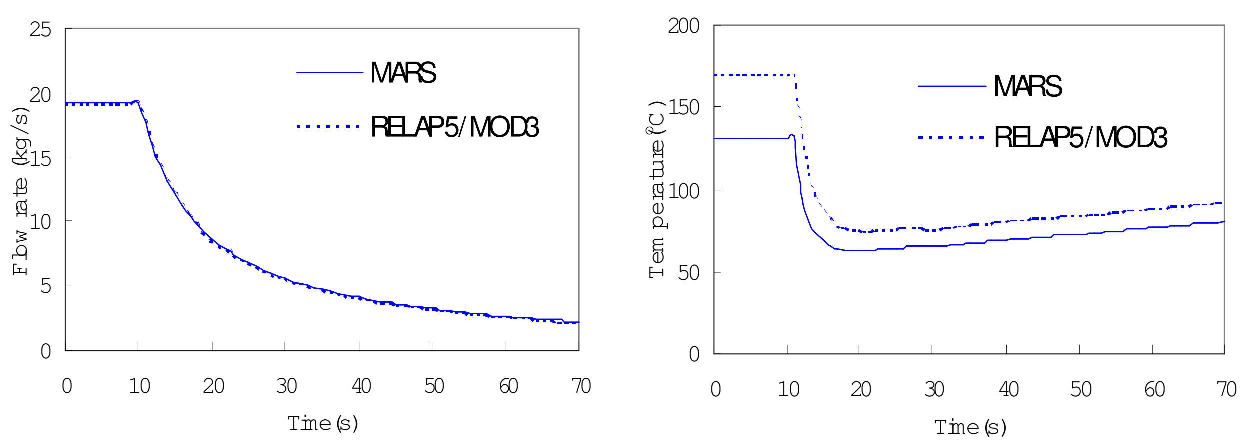

Figure 8. Comparison of flow rate and fuel temperature for RELAP5 and MARS-h

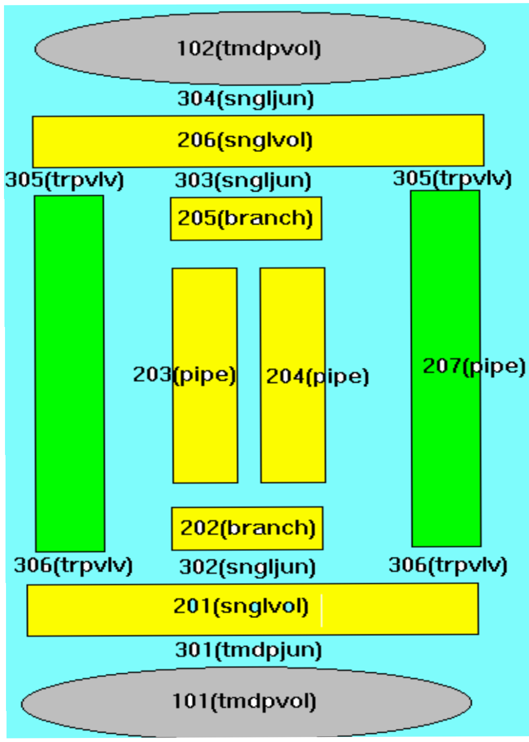

Figure 8. Nodalization of SPERT for MARS-h simulation

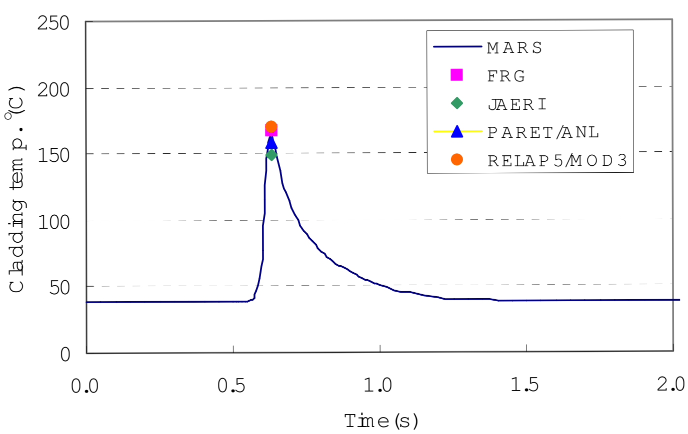

Fig. 9 Predicted peak cladding temperature at reactivity induced transient

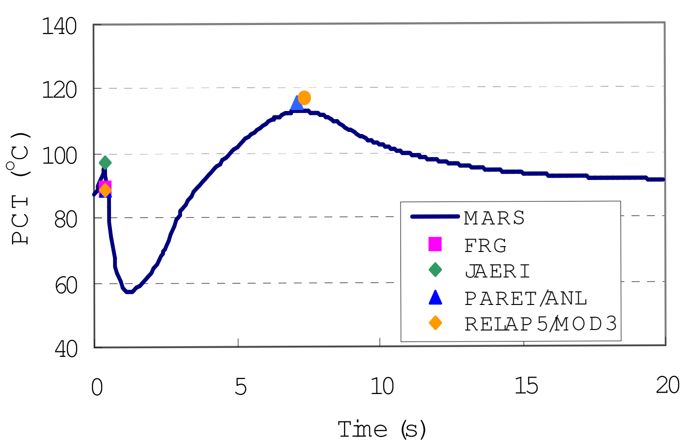

Fig. 10 Predicted peak cladding temperature at loss of flow transient